HIGH

ENERGY

Bruce J. King (BNL)

bking@bnl.gov

MUON

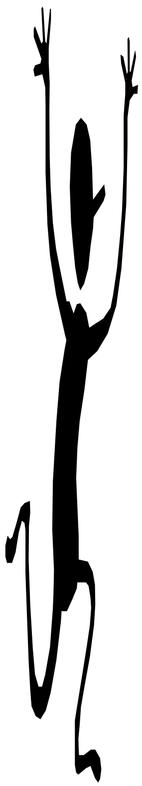
http://pubweb.bnl.gov/people/bking

COLLIDERS

MOTIVATION

WHY MUONS?

Electrons
are too light



Discovery reach
of a few TeV ?

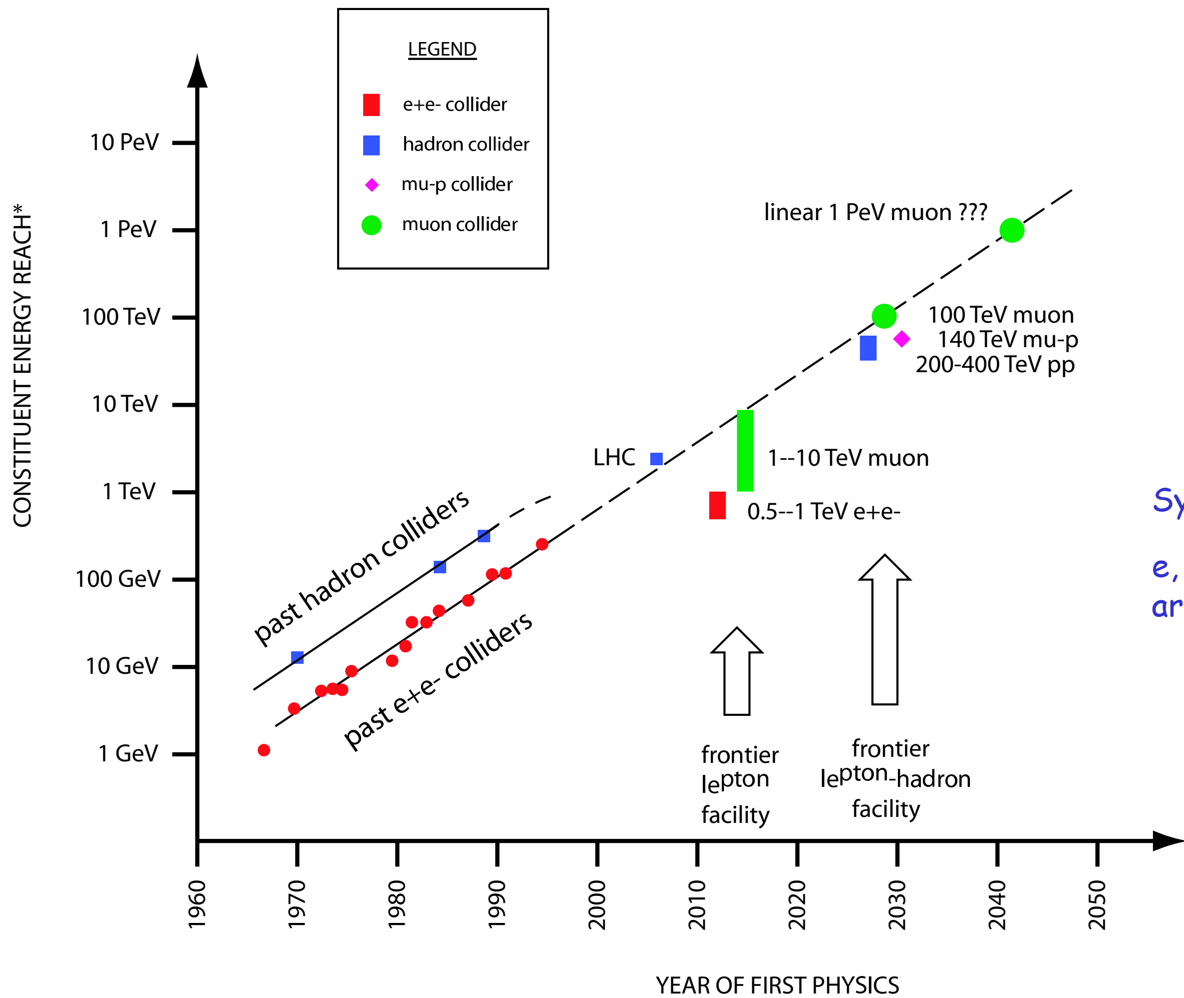
Protons are strongly
interacting &
composite

Discovery reach of a
few 10's of TeV ?

⇨ **Muons**, though
unstable & untested

Discovery reach of
100-1000 TeV ??

PLAUSIBLE FUTURE WITH MUON COLLIDERS



Symbiotic!

e, p and μ technologies are working together

* assume constituent energy reach for hadrons = 1/6 x CoM energy

HEP MOTIVATION

Keeping on "Livingston curve"

- Generally, discoveries come from more energy
- What is needed next to stay on the curve?
- LHC "reaches" to about 5 TeV.
- We usually increase by factor π
- The next machine should be at 15 TeV (for p-p about 25+25 TeV)
- Luminosity depends on physics, LHC should point the way
- (If no signposts at LHC, maybe hard to sell)

Slide from Bill Willis (Columbia U.)

"HEMC'99 Summary"

HEMC'99 Workshop,

Montauk, NY, Sept'99

STUDIES ON ENERGY FRONTIER MUON COLLIDERS

MUON COLLIDER COLLABORATION STUDIES

The bulk of the work on energy frontier muon colliders has been done by the then-named Muon Collider Collaboration. Now named the "Neutrino Factory and Muon Collider Collaboration" or "Muon Collaboration", their focus has shifted to the related technology of neutrino factories although they are also sponsoring a study on "From the Neutrino Factory to the Higgs Factory: Muons all the Way". Their 2 main publications on muon colliders are:

"$\mu^+\mu^-$ Collider; a Feasibility Study"
(83 authors)
BNL-52503, Fermilab-Conf-96/092, LBNL-38946
("the Snowmass book")

"Status of Muon Collider Research and Development and Future Plans"
(108 authors)
Phys. Rev. Special Topics, Accel. Beams 2, 081001 (1999)
("the status report")


HEMC'99 Workshop
• a 5-day workshop of 48 accelerator & HE physicists; Montauk, NY, USA, Sept-Oct,1999.
• a first assessment of the long-term potential for very High Energy Muon Colliders.
http://pubweb.bnl.gov/people/bking/heshop
AIP Conference Proceedings 530

6-MONTH STUDY

Oct'00 – Apr'01

- a very cheap, open study based on emails and web page; mailing list 156 Muon Collab. (automatic) + 144 non-Collab.
- purpose was to keep muon collider R&D ticking over until the field backs up its words of support for long-term accelerator R&D
- organized by Allen Caldwell (HEP) & BJK (accelerator)
- proceedings in publication on CD-ROMs (Rinton Press)

http://pubweb.bnl.gov/people/bking/mucoll

SNOWMASS!

Will explore potential for HEP future with energy frontier muon colliders such as:

1) "mu-LCs" at E_{CoM}=1.6-10 TeV

(add-on muon colliders using linac from TeV-scale e+e- linear collider)

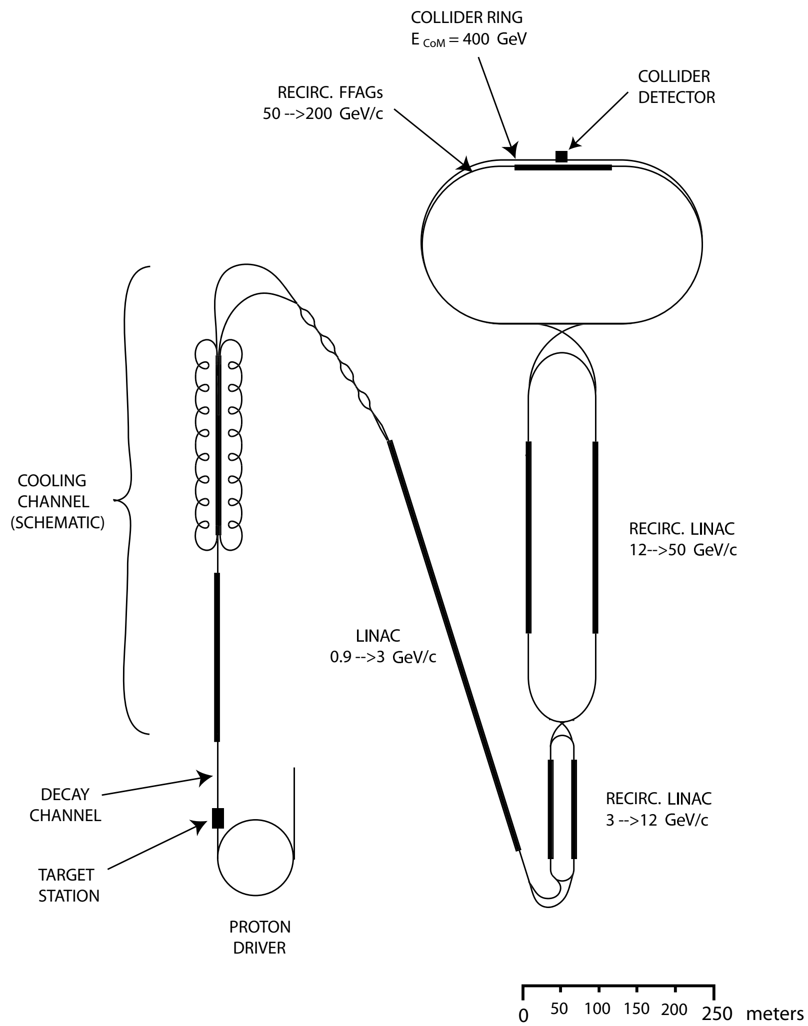
2) 100 TeV Very Large Muon Collider (VLMC)

... which can share facilities with a VLHC

http://pubweb.bnl.gov/people/bking/Snowmass-mumu

POSSIBLE REALIZATIONS

STAND-ALONE MUON COLLIDER



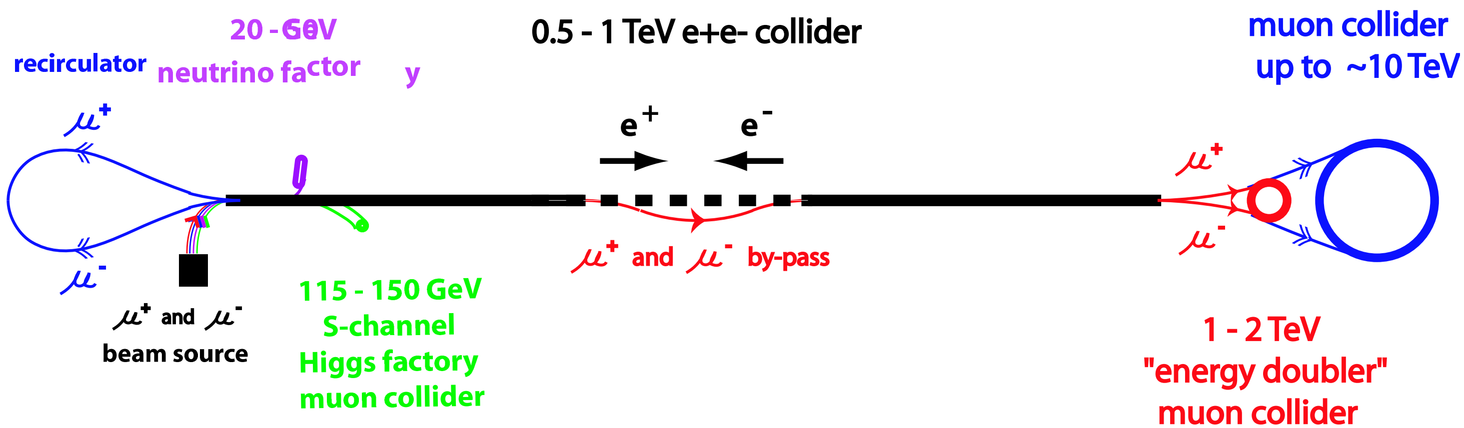
This is an example footprint for a 400 GeV muon collider.

"Mu-LC"

SYMBIOTIC FACILITY: LINEAR e^+e^- COLLIDER + MUON COLLIDER

First discussed by D. Neuffer, H. Edwards & D. Finley in Proc. Snowmass'96

Works better for larger, superconducting cavities ("TESLA")



CHALLENGES: a) design of (very) high performance muon cooling channel, **b)** integration into e+e- collider design, **c)** major design constraints & luminosity cap to greatly suppress neutrino radiation

(worst case < 10^{-2} mSv/yr ~ 0.003 x U.S natural bkgrd. rad.)

POTENTIAL: $E_{CoM} \to 10$ TeV with $\mathcal{L} \sim 1\times10^{34}\ \mathrm{cm}^{-2}.\mathrm{s}^{-1}$ (+ neutrino, s-channel Higgs factories)

HEP results (LHC, Tevatron, ν physics) will decide the actual add-ons: "Swiss army knife accelerator"

Plausible new energy frontier lab.:

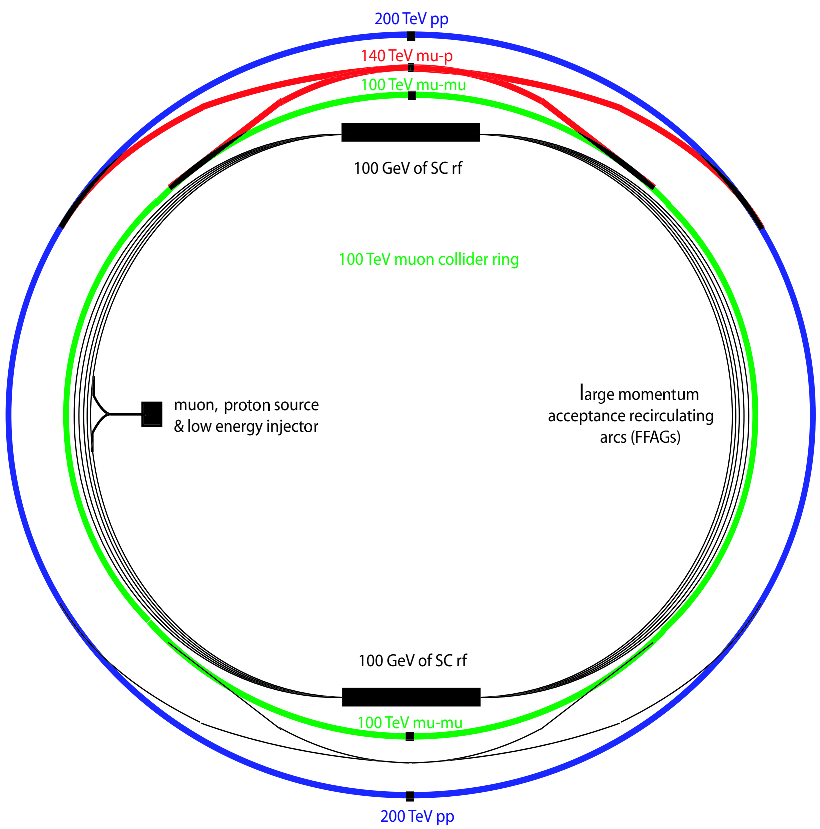
100 TeV VLMC with VLHC

Neutrino radiation => new, very isolated lab. for high luminosity Very Large Muon Collider (VLMC).

On balance, technical difficulties not much worse than for lower energy muon colliders.

(slightly less cooling needed; recent 30 TeV final focus design by Raimondi)

Schematic Layout showing Acceleration,
Muon Collider, Proton Collider & mu-p Collider



VLMC + VLHC symbiosis

- ✓ common magnet R&D
- ✓ same tunnel, or side-by-side
- ✓ common acceleration to ~50 TeV/beam
  - ➢ full energy for muon collider
  - ➢ ~½ energy for hadron collider
- ✓ mu-p collisions at E_{CoM} ~ 140 TeV

“STRAW-MAN” MUON COLLIDER PARAMETER SETS for SNOWMASS

VLMC @ 100 TeV

&

mu-LC @ 1.6-10 TeV

SUMMARY

• Muon colliders could play a central role in extending the HEP energy frontier.

• **<u>"This is exciting! How can I help?"</u>** Come to the Snowmass sessions &/or send an email to bking@bnl.gov .

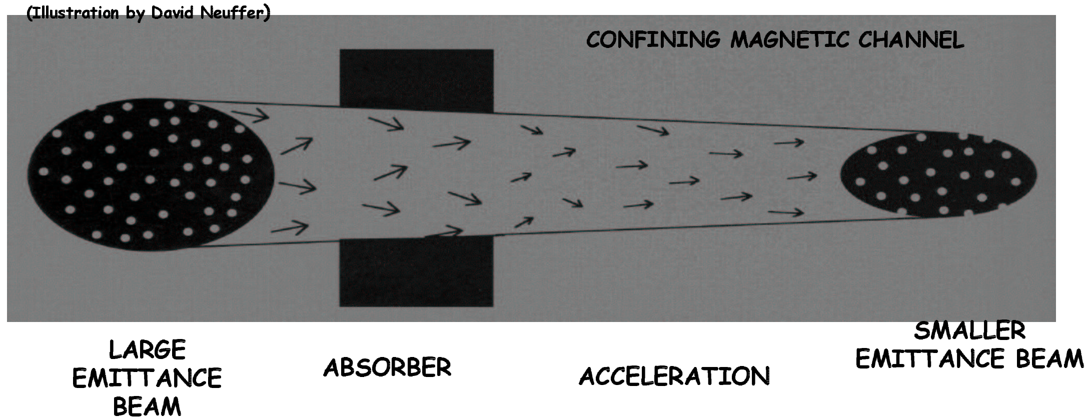
IONIZATION BEAM COOLING:

SIGNATURE TECHNOLOGY & DOMINANT TECHNICAL CHALLENGE

"IT'S THE COOLING"

Simple concept:

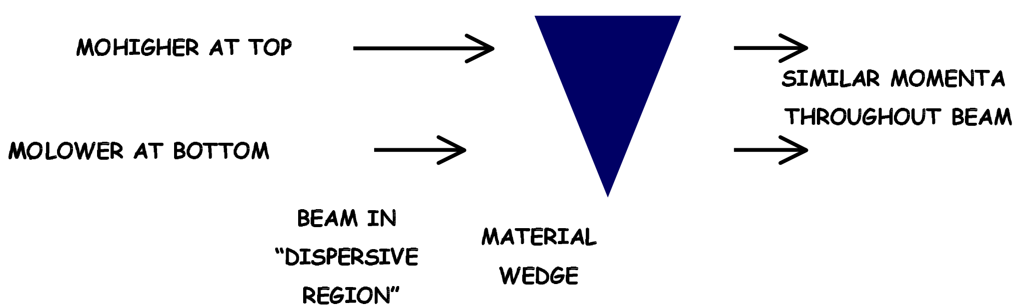
(Illustration by David Neuffer)



However, Coulomb scattering and energy straggling compete with cooling,

A) confines cooling to a difficult region of parameter space (low energy, large angles)

B) need to control beam energy spread to obtain required ~10^6 reduction in 6-D phase space:



"emittance exchange"

COOLING: WHAT WE HAVE & WHAT WE NEED NEXT

We have:

a) general theoretical scenarios & specs. to reach the desired 6-D emittances

b) detailed particle-by-particle tracking codes (modified GEANT,ICOOL) & (new) higher order matrix tracking code (modified COSY-infinity) + (new) wake field code interface

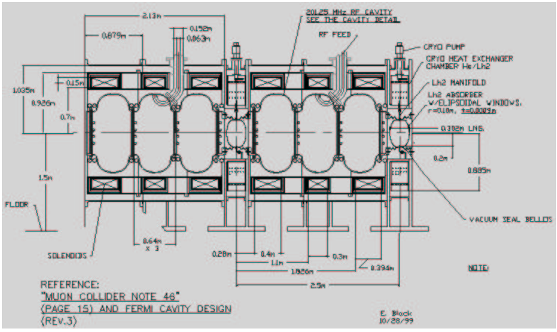
c) engineering designs of pieces

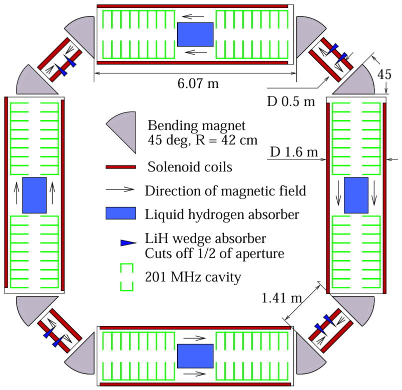
d) neutrino factory designs for factor of ~10 *transverse* cooling

e) "ring cooler" design for MUCOOL expt. with predicted full 6-D cooling by factor of ~32

(c.f. muon collider needs ~10^6 ~ 32^4)

2 sub-units of a cooling stage (Black, IIT)





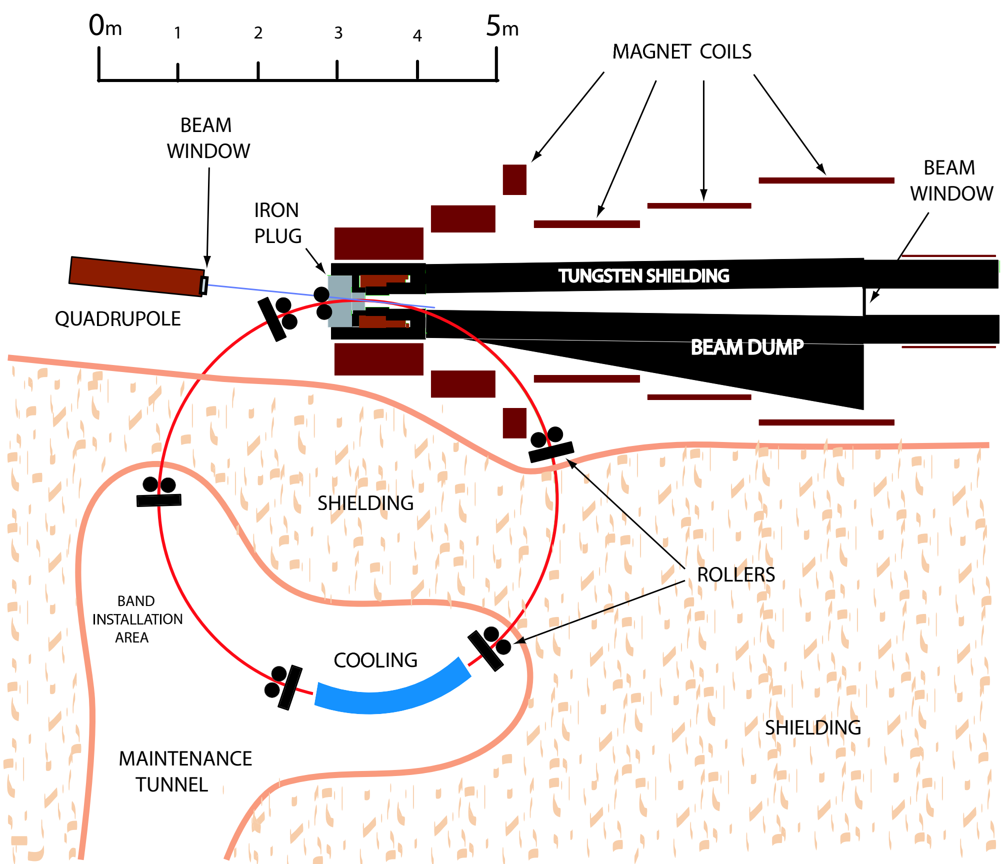
"ring cooler"

(Balbekov, FNAL)

But we have yet to put the pieces together to "build the muon collider cooling channel on a computer" => This is our #1 item of business

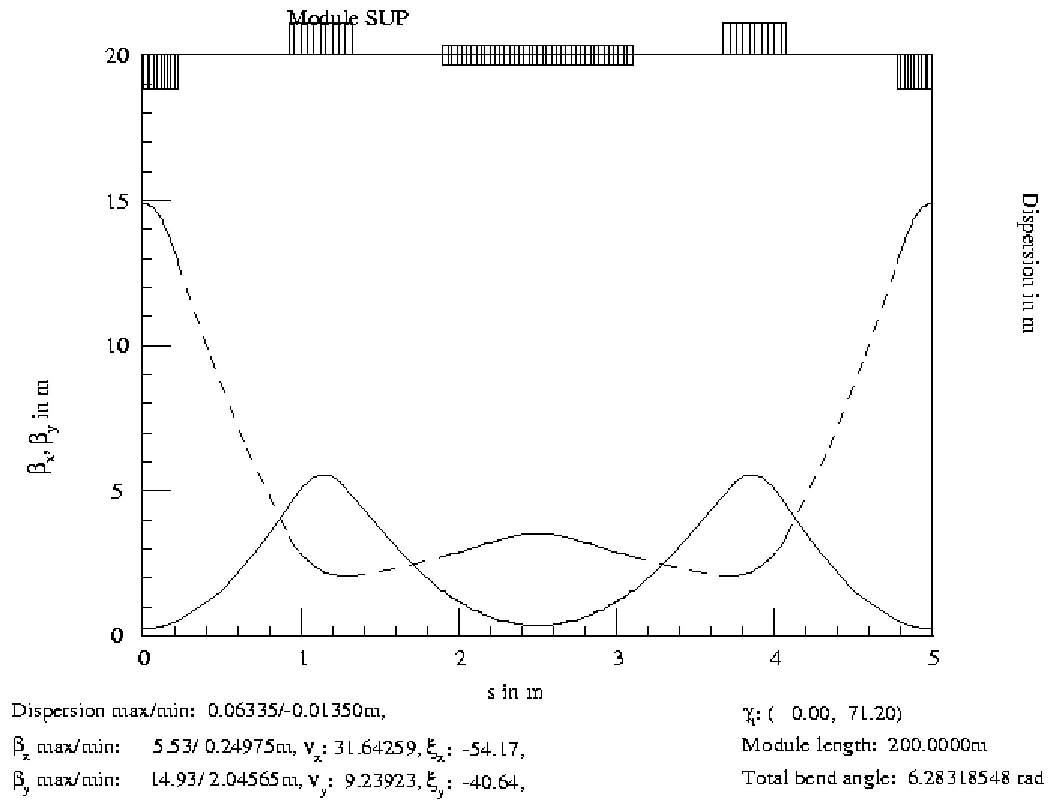
OTHER CHALLENGES

TARGETRY



The figure is a rotating band geometry for a water-cooled inconel, nickel or titanium-alloy target that appears capable of efficient pion production from Megawatt-scale pulsed proton beams. Presented as King, Mokhov, Simos & Weggel poster TPAH136.

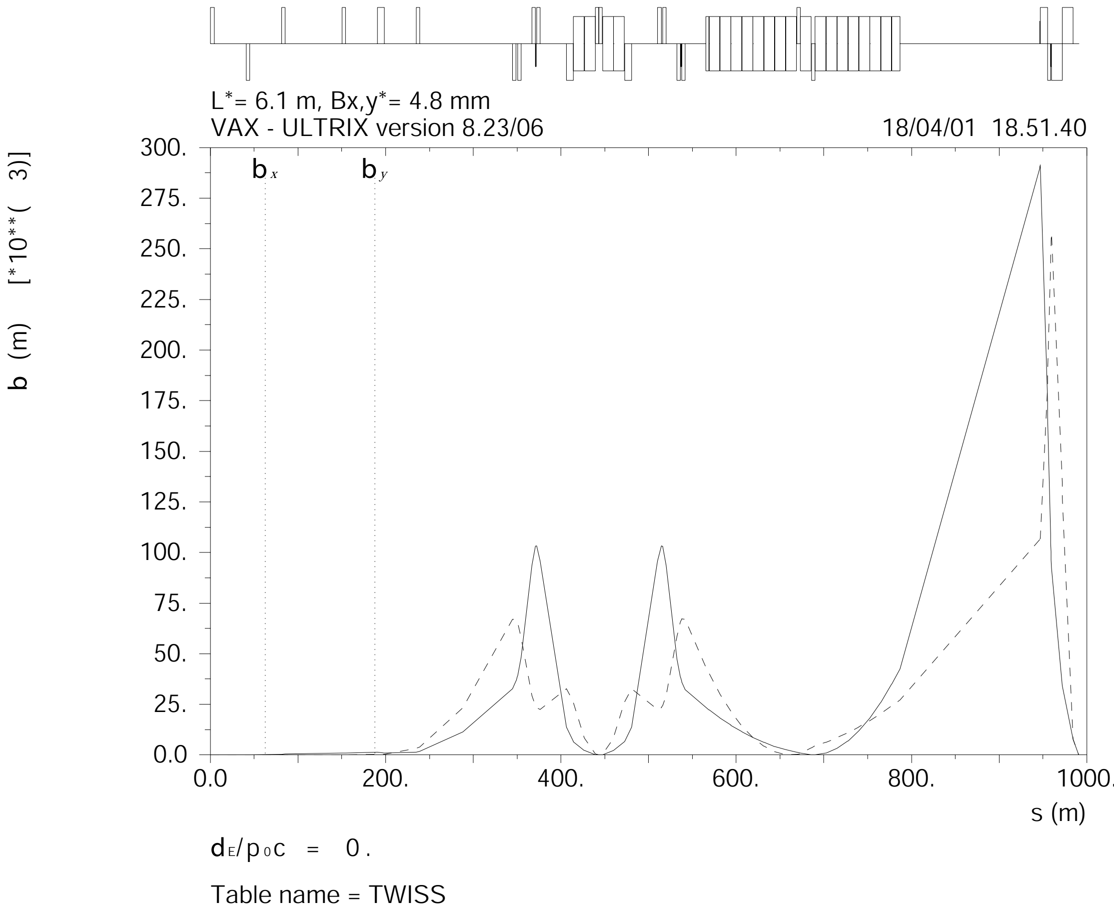
ACCELERATION



Acceleration will be the main cost driver for energy frontier muon colliders. Cost reduction => acceleration in (e.g.) FFAG lattices.

The figure shows a module of an FFAG lattice for 10->20 GeV by Trbojevic (+ Courant & Garren); a much higher energy version of this or similar – 25->50 TeV – would be needed for the 100 TeV VLMC.

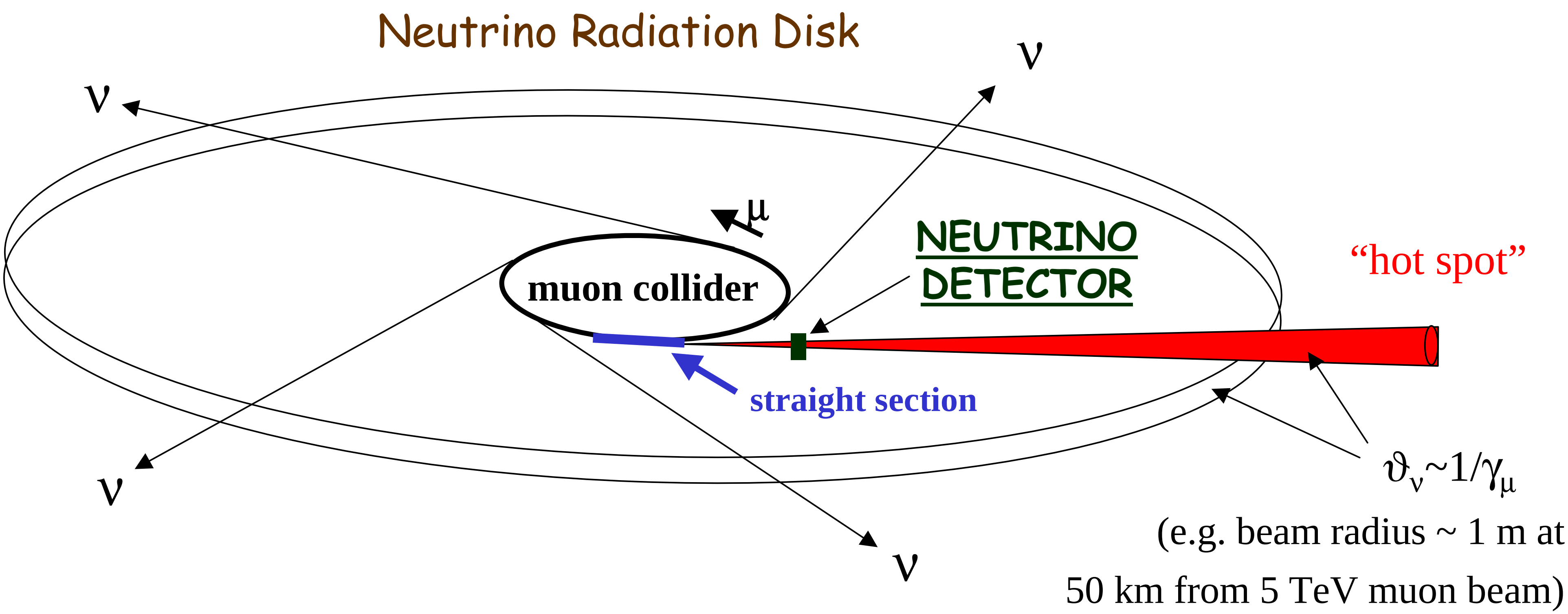
COLLIDER RING



The figure shows a recent breakthrough in final focus design for VLMC's: a 30 TeV final focus with beta*=4.8 mm (Raimondi, SLAC)

Ref. Raimondi & Zimmermann, CD Proc. 6-Month Study on Muon Colliders; Oct'00 – Apr'01

NEUTRINO RADIATION

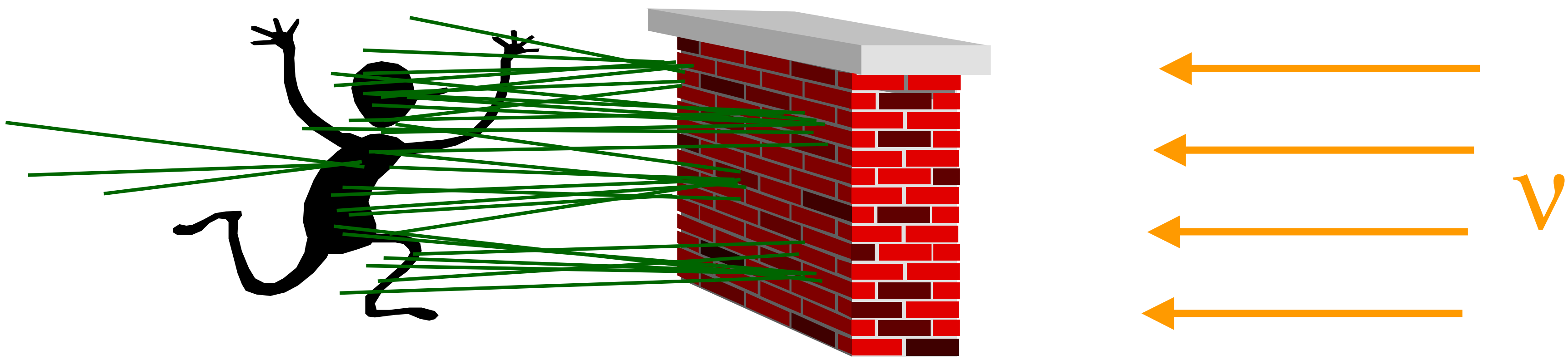


ν's give additional physics + pose extra challenges

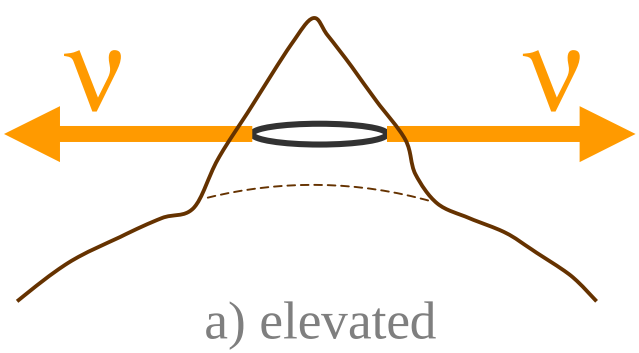
*ref. B.J. King, " Potential Hazards from Neutrino Radiation at Muon Colliders", **physics/9908017**; B.J. King, "Neutrino Radiation Challenges and Proposed Solutions for Many-TeV Muon Colliders", Proc. HEMC'99, **hep-ex/0005006**.

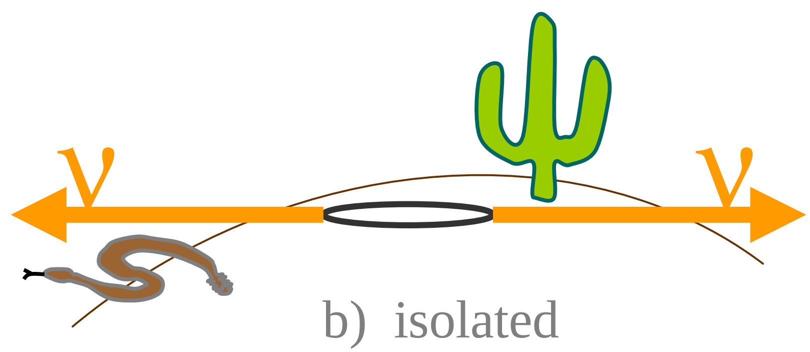
<u>THE RADIATION HAZARD !!</u>

The hazard is charged particles from neutrino interactions in the surroundings ...



The predicted dose rises sharply with collider energy. Many-TeV colliders with very high luminosities may need to be located at specially chosen sites, e.g.:





MAGNET COSTS

Slides from Mike Harrison (BNL)

"Magnet Challenges: Technology and Affordability"

HEMC'99 Workshop,

Montauk, NY, Sept'99

Affordability

- RHIC Dipoles 8cm, 10m, 4T, FY95 cost $110K each
- HEMC Dipole
  - 8cm -> 15cm 50%
  - 4T -> 7T 50%
  - 10m -> 15m 40%
  - FY95 -> FY00 15%
  - Estimate HEMC Dipole $400K or $26K/m based on RHIC
- 10 Tev needs 15km circumference -> magnet costs ~$400M. Ring costs = dipoles x 3(or4) = $1.2(6)B (probably a lower bound since HEMC dipoles are more complex than RHIC)

ENCOURAGING!

Caveat: collider ring only; acceleration may be a few times this.

Conclusions

- A 10 Tev machine based on Nb-Ti magnets (7T dipole) is challenging but possible
- A 100 Tev machine does not look feasible based on 10T cosine theta dipoles
- A different magnet design (no mid plane cryogenics) would help
- Newer technologies (Nb3Sn, HTS) would be beneficial assuming that costs are reasonable and they work